CLAIMS

1. A method for increasing the strength of a volume of soil, particularly for containing and supporting excavation faces, characterized in that it comprises at least one reinforcement step that comprises the following steps:

- a step for preparing receptacles for a reinforcement structure, in which a plurality of mutually spaced reinforcement holes are formed, said holes being arranged substantially vertically or inclined with respect to a vertical direction in the volume of soil to be strengthened;
- a step for inserting the reinforcement structure, during which reinforcement elements are inserted in said reinforcement holes;
- a step for locking the reinforcement structure, during which a synthetic locking substance that expands by chemical reaction is injected into said reinforcement holes, said substance being adapted to bond said reinforcement elements with the surrounding soil.

2. The method according to claim 1, characterized in that said reinforcement holes and said reinforcement elements are inclined with respect to the vertical on a plane that is parallel to the excavation face.

3. The method according to claim 1, characterized in that said reinforcement holes and said reinforcement elements are inclined with respect to the vertical on a vertical plane that is perpendicular to the excavation face.

4. The method according to claim 1, characterized in that said reinforcement holes and said reinforcement elements are inclined with respect to the vertical on a plane that is parallel to the excavation face and on a vertical plane that is perpendicular to the excavation face.

5. The method according to one or more of the preceding claims, characterized in that said reinforcement holes and said reinforcement elements are inclined with respect to the vertical toward the volume of soil to be strengthened.

6. The method according to one or more of the preceding claims, characterized in that said reinforcement holes are provided at a distance from the excavation face to be produced or from the exposed face of the volume of soil to be strengthened that is substantially comprised between 0.10 m and 2.00 m.

7. The method according to one or more of the preceding claims, characterized in that the distance between two contiguous reinforcement holes is substantially comprised between 0.20 m and 2 m.

8. The method according to one or more of the preceding claims, characterized in that said reinforcement holes have a diameter that is substantially comprised between 12 mm and 180 mm.

9. The method according to one or more of the preceding claims, characterized in that said reinforcement holes are arranged, in plan view, in rows that are substantially parallel to the excavation face or to the exposed face of the volume of soil to be strengthened.

10. The method according to one or more of the preceding claims, characterized in that the distance between two contiguous rows of said reinforcement holes is substantially comprised between 0.10 m and 2.00 m.

11. The method according to one or more of the preceding claims, characterized in that said reinforcement holes and/or said reinforcement elements have such a length as to pass through the natural lie of the excavation face or the deep slip surface of the volume of soil to be strengthened.

12. The method according to one or more of the preceding claims, characterized in that said reinforcement holes and/or said reinforcement elements have such a length as to penetrate for at least 0.5 m in the soil that lies below the natural lie of the excavation face or the deep slip surface of the volume of soil to be strengthened.

13. The method according to one or more of the preceding claims, characterized in that said reinforcement elements have a tensile strength of

more than 5 MPa.

14. The method according to one or more of the preceding claims, characterized in that said reinforcement elements have a shear strength of more than 0.3 MPa.

15. The method according to one or more of the preceding claims, characterized in that said reinforcement elements are constituted, for each one of said reinforcement holes, by a bar that can be inserted in the corresponding reinforcement hole.

16. The method according to one or more of the preceding claims, characterized in that said bar has a solid cross-section whose diameter is smaller than the corresponding reinforcement hole.

17. The method according to one or more of the preceding claims, characterized in that said bar is constituted by a tubular element with openings on its side surface, said tubular element having a diameter that is smaller than, or equal to, the diameter of the corresponding reinforcement hole.

18. The method according to one or more of the preceding claims, characterized in that said tubular elements that constitute said reinforcement elements have an outside diameter that is substantially comprised between 12 mm and 180 mm and an inside diameter that is substantially comprised between 8 mm and 150 mm.

19. The method according to one or more of the preceding claims, characterized in that the lateral openings formed in the lateral surface of said tubular elements that constitute the reinforcement elements occupy at least 30% of the lateral surface of said tubular elements.

20. The method according to one or more of the preceding claims, characterized in that during said locking step the synthetic locking substance is injected into the reinforcement holes laterally to the corresponding reinforcement element.

21. The method according to one or more of the preceding claims,

characterized in that during said locking step the synthetic locking substance is injected into the reinforcement holes inside the corresponding tubular element that constitutes the reinforcement bar.

22. The method according to one or more of the preceding claims, characterized in that the upper end of said reinforcement elements is anchored to the soil located outside the thrust wedge or to the foundation structure of an existing building that is crossed by said reinforcement holes.

23. The method according to one or more of the preceding claims, characterized in that it comprises a step for consolidating the volume of soil to be strengthened, said step comprising the following steps:

- a drilling step, in which a plurality of injection holes are produced, said holes being mutually spaced and being arranged substantially vertically or inclined with respect to a vertical direction within the volume of soil whose resistance to all the various stresses is to be increased;
- an injection step, in which a synthetic consolidation substance is injected into said injection holes, said substance expanding by chemical reaction and being adapted to compact, as a consequence of its expansion, the surrounding soil.

24. The method according to one or more of the preceding claims, characterized in that said injection holes are produced at a distance from the excavation face to be produced or from the exposed face of the volume of soil to be strengthened that is substantially comprised between 0.10 m and 2.00 m.

25. The method according to one or more of the preceding claims, characterized in that the distance between two contiguous injection holes is substantially comprised between 0.20 m and 2 m.

26. The method according to one or more of the preceding claims, characterized in that said injection holes have a diameter substantially comprised between 12 mm and 180 mm.

27. The method according to one or more of the preceding claims,

characterized in that said injection holes are arranged, in plan view, in rows that are substantially parallel to the excavation face or to the exposed face of the volume of soil to be strengthened.

28. The method according to one or more of the preceding claims, characterized in that the distance between two contiguous rows of said injection holes is substantially comprised between 0.10 m and 2.00 m.

29. The method according to one or more of the preceding claims, characterized in that in said injection step and/or in said locking step, the synthetic substance is injected by means of injection tubes that are inserted in the corresponding injection holes and/or in the corresponding reinforcement holes, gradually extracting the injection tube from the corresponding injection hole and/or from the corresponding reinforcement hole.

30. The method according to one or more of the preceding claims, characterized in that said injection tubes used in said consolidation step and/or in said reinforcement step have a diameter that is substantially comprised between 6 mm and 30 mm.

31. The method according to one or more of the preceding claims, characterized in that at least the outer surface of said injection tubes used in said consolidation step and/or in said reinforcement step is made of, or treated with, a lubricating substance in order to facilitate its extraction from said injection holes and/or from said reinforcement holes.

32. The method according to one or more of the preceding claims, characterized in that the rate of extraction of the injection tube from the corresponding injection hole and/or from the corresponding reinforcement hole and/or the flow rate of synthetic substance delivered during extraction in said injection step or in said locking step is changed according to the stratigraphic characteristics of the soil crossed by the injection hole and/or by the reinforcement hole in order to deliver larger quantities of synthetic substance in weaker layers of the soil and smaller quantities of synthetic

substance in stronger layers of the soil.

33. The method according to one or more of the preceding claims, characterized in that the injection pressure of said synthetic substance is substantially comprised between 5 and 30 bar.

34. The method according to one or more of the preceding claims, characterized in that said synthetic substance has a modulus of elasticity on the same order of magnitude as the modulus of elasticity of the soil in which it is injected, i.e., less than 500 MPa.

35. The method according to one or more of the preceding claims, characterized in that the chemical expansion reaction of said synthetic substance is not affected by the presence of water in the surrounding soil.

36. The method according to one or more of the preceding claims, characterized in that said synthetic substance, after expansion, cannot be altered by the presence of water in the surrounding soil.

37. The method according to one or more of the preceding claims, characterized in that said synthetic substance is constituted by a closed-cell polyurethane foam.

38. The method according to one or more of the preceding claims, characterized in that said synthetic substance is constituted by an MDI isocyanate and by a mixture of polyols.

39. The method according to one or more of the preceding claims, characterized in that said consolidation step is performed before said reinforcement step.

40. The method according to one or more of the preceding claims, characterized in that said synthetic consolidation substance has a potential volume increase substantially comprised between 2 and 30 times the volume of said synthetic substance prior to expansion.

41. The method according to one or more of the preceding claims, characterized in that said synthetic consolidation substance has a potential volume increase substantially comprised between 5 and 30 times the volume

of said synthetic substance prior to expansion.

42. The method according to one or more of the preceding claims, characterized in that said synthetic consolidation substance has a reaction time substantially comprised between 2 and 80 seconds.

43. The method according to one or more of the preceding claims, characterized in that said synthetic consolidation substance has a reaction time substantially comprised between 2 and 15 seconds.

44. The method according to one or more of the preceding claims, characterized in that said synthetic consolidation substance has a maximum expansion pressure that is higher than the tension in the volume of soil to be strengthened.

45. The method according to one or more of the preceding claims, characterized in that said synthetic consolidation substance has a maximum expansion pressure, in fully confined conditions, that is substantially comprised between 200 KPa and 10,000 KPa.

46. The method according to one or more of the preceding claims, characterized in that said synthetic consolidation substance has a maximum expansion pressure of substantially more than 500 KPa.

47. The method according to one or more of the preceding claims, characterized in that said synthetic consolidation substance, prior to the chemical expansion reaction, has a viscosity substantially comprised between 100 mPa·s and 700 mPa·s at 25° C.

48. The method according to one or more of the preceding claims, characterized in that the viscosity of said synthetic consolidation substance passes from a value comprised between 100 mPa·s and 700 mPa·s to a value that tends to infinity in a time interval comprised between 5 and 20 seconds starting from the beginning of the chemical expansion reaction.

49. The method according to one or more of the preceding claims, characterized in that said synthetic consolidation substance has, after expansion, in conditions in which expansion is not confined, a density of

substantially 30 Kg/m^3.

50. The method according to one or more of the preceding claims, characterized in that said synthetic consolidation substance, once injected into the soil and hardened, has a density substantially comprised between 100 Kg/m^3 and 400 Kg/m^3.

51. The method according to one or more of the preceding claims, characterized in that said synthetic consolidation substance, once injected and hardened, has a tensile strength that is substantially comprised between 0.75 MPa and 5.50 MPa respectively at the densities of 100 kg/m^3 and 400 kg/m^3.

52. The method according to one or more of the preceding claims, characterized in that said synthetic consolidation substance, once injected and hardened, has a compressive strength that is substantially comprised between 0.68 MPa and 8.78 MPa respectively at the densities of 100 kg/m^3 and 400 Kg/m^3.

53. The method according to one or more of the preceding claims, characterized in that said synthetic consolidation substance, once injected and hardened, has a flexural strength that is essentially comprised between 0.95 MPa and 6.00 MPa respectively at the densities of 100 kg/m^3 and 400 kg/m^3.

54. The method according to one or more of the preceding claims, characterized in that the synthetic consolidation substance, once injected and hardened, has a shear strength substantially comprised between 0.34 MPa and 4.39 MPa respectively at the densities of 100 kg/m^3 and 400 kg/m^3.

55. The method according to one or more of the preceding claims, characterized in that said synthetic locking substance has a potential volume increase substantially comprised between 1 and 5 times the volume of said synthetic substance prior to expansion.

56. The method according to one or more of the preceding claims,

characterized in that said synthetic locking substance has a reaction time substantially comprised between 2 and 80 seconds.

57. The method according to one or more of the preceding claims, characterized in that said synthetic locking substance has a maximum expansion pressure that is lower than the limit breaking pressure of the contiguous soil affected by the consolidation step.

58. The method according to one or more of the preceding claims, characterized in that said synthetic locking substance has a significant decrease in the maximum expansion pressure (dissipation) following a degree of expansion thereof of 5%, or less.

59. The method according to one or more of the preceding claims, characterized in that said synthetic locking substance has a maximum expansion pressure, in fully confined conditions, that is comprised between 20 KPa and 200 KPa.

60. The method according to one or more of the preceding claims, characterized in that said synthetic locking substance, prior to the chemical expansion reaction, has a viscosity substantially comprised between 100 mPa·s and 500 mPa·s at 25° C.

61. The method according to one or more of the preceding claims, characterized in that the viscosity of said synthetic locking substance passes from a value comprised between 100 mPa·s and 500 mPa·s at 25° C to a value that tends to infinity in a time interval comprised between 10 and 80 seconds starting from the beginning of the chemical expansion reaction.

62. The method according to one or more of the preceding claims, characterized in that said synthetic locking substance has, after expansion, in non-confined expansion conditions, a density of at least 200 Kg/m^3.

63. The method according to one or more of the preceding claims, characterized in that said synthetic locking substance, once injected into the soil and hardened, has a density substantially comprised between 400 Kg/m^3 and 800 Kg/m^3.

64. The method according to one or more of the preceding claims, characterized in that said synthetic locking substance, once injected and hardened, has a tensile strength substantially comprised between 5.60 MPa and 17.80 mPa respectively at the densities of 400 kg/m^3 and 800 kg/m^3.

65. The method according to one or more of the preceding claims, characterized in that said synthetic locking substance, once injected and hardened, has a compressive strength substantially comprised between 8.78 MPa and 34.42 MPa respectively at the densities of 400 kg/m^3 and 800 kg/m^3.

66. The method according to one or more of the preceding claims, characterized in that said synthetic locking substance, once injected and hardened, has a flexural strength substantially comprised between 7.18 MPa and 11.98 MPa respectively at the densities of 400 kg/m^3 and 800 kg/m^3.

67. The method according to one or more of the preceding claims, characterized in that said synthetic locking substance, once injected and hardened, has a shear strength substantially comprised between 4.40 MPa and 17.20 MPa respectively at the densities of 400 kg/m^3 and 800 kg/m^3.

68. The method according to one or more of the preceding claims, characterized in that said consolidation step is performed substantially simultaneously with said reinforcement step.

69. The method according to one or more of the preceding claims, characterized in that said consolidation step is performed substantially simultaneously with said reinforcement step by producing said reinforcement holes and said injection holes, inserting in said reinforcement holes said reinforcement elements and then injecting said synthetic consolidation substance into said injection holes and said synthetic locking substance into said reinforcement holes.

70. The method according to one or more of the preceding claims, characterized in that the synthetic locking substance used in said reinforcement step, in the absence of said consolidation step or when

performing said reinforcement step substantially simultaneously with said consolidation step, has a maximum expansion pressure, in fully confined conditions, comprised between 20 KPa and 10,000 KPa.

71. The method according to one or more of the preceding claims, characterized in that the synthetic locking substance used in said reinforcement step, in the absence of said consolidation step or when performing said reinforcement step substantially simultaneously with said consolidation step, once injected into the soil and hardened, has a density substantially comprised between 250 kg/m^3 and 400 kg/m^3.

72. The method according to one or more of the preceding claims, characterized in that the synthetic locking substance injected into the reinforcement holes in said reinforcement step, in the absence of said consolidation step or when performing said reinforcement step substantially simultaneously with said consolidation step, is constituted by said synthetic consolidation substance.